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A synthesis of single scattering albedo of biomass burning aerosol over southern Africa during SAFARI 2000

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[1] We present a synthesis of single scattering albedo for biomass burning aerosol from the SAFARI 2000 field campaign. Values at 550 nm were derived from three methods: airborne in situ measurements of aerosol scattering and absorption; airborne flux radiometry; and ground-based sun-photometer/radiometer retrievals from AERONET. Collocated comparisons indicate that uncertainties are well understood for all three methods. The new (Version 2) AERONET retrieval gives substantially lower single scattering albedo over bright surfaces, and the comparisons herein represent the first independent check of this retrieval. Combined in situ and AERONET data yield a regional value of 0.85 ± 0.02 (mean and total uncertainty), which we propose is representative of single scattering albedo for the Southern African region during the biomass burning season. This value agrees with the "highly absorbing smoke" model used in MODIS aerosol retrievals, but indicates that many of the AeroCom models overestimate single scattering albedo for this region and season. **Citation:** Leahy, L. V., T. L. Anderson, T. F. Eck, and R. W. Bergstrom (2007), A synthesis of single scattering albedo of biomass burning aerosol over southern Africa during SAFARI 2000, *Geophys. Res. Lett.*, *34*, L12814, doi:10.1029/2007GL029697.

1. Introduction

[2] Aerosol direct climate forcing (DCF) describes the modification of Earth's energy balance due to the direct interaction of anthropogenic aerosols with solar radiation. Estimates using chemical transport/radiative transfer models (CTRTMs) indicate that global-mean DCF is negative, i.e. a cooling effect, and may compensate for a substantial fraction of positive forcing by greenhouse gases [*Charlson et al.*, 1991; *Ramaswamy et al.*, 2001]. Aerosol optical properties controlling DCF are highly variable and not always accurately represented in CTRTMs. For example, *Bates et al.* [2006] found that estimates of DCF for three regions increased in magnitude by an average of 37% when model-derived aerosol optical properties were replaced with measured properties specific to each region.

[3] Mid-visible single scattering albedo, ω - the ratio of aerosol light scattering to aerosol light extinction - is among the most important of aerosol optical properties for determining DCF as well as one of the most challenging to measure [*Heintzenberg et al.*, 1997]. The goal of this study is to constrain the regional-mean value of ω for biomass burning aerosol over Southern Africa, suitable for use in CTRTM calculations. We use measurements acquired during the Southern African Regional Science Initiative (SAFARI) 2000 field campaign [*Swap et al.*, 2003], in a two-step process. First, we analyze collocated, independent measurements to provide a robust estimate of measurement uncertainty. We then compare and integrate data from the two techniques that provide regional-scale characterization - airborne in situ measurements from multiple flights and ground-based radiometry from several continuously operating stations.

2. Data Sets

[4] Full details on instrumentation, data reduction, and uncertainty derivation are given by *Sinha et al.* [2003, Appendix A], *Magi et al.* [2003], *Bergstrom et al.* [2003], *Schmid et al.* [2003], and *Eck et al.* [2003]. A brief description follows.

2.1. In Situ

[5] Aerosol scattering coefficient (σ_s) and aerosol absorption coefficient (σ_a) at 550 nm wavelength and low relative humidity (RH) were measured aboard the University of Washington (UW) research aircraft using, respectively, an MS Electron integrating nephelometer and a Radiance Research Particle Soot Absorption Photometer (PSAP). These provide a direct measurement of low-RH ω at 550 nm (ω_{550}) as the ratio of σ_s to the aerosol extinction coefficient ($\sigma_s + \sigma_a$). Adjustment to ambient RH was based on humidified nephelometry measurements [*Magi and Hobbs*, 2003] and an assumption that RH has no effect on σ_a. Because scattering humidification factors were very low (ranging from 1.0 to 1.2), the error associated with this assumption is negligible.

[6] The passing efficiency of the isokinetic aerosol inlet is not well known. The 50% cut-point diameter of an inlet with nearly identical specifications was estimated to be 4 μm [*Sinha et al.*, 2003]. Data from the seven AERONET sites analyzed herein indicate that the ratio of fine to total aerosol extinction (separated at 1.2 μm diameter) was 0.89–0.96. Therefore, we assume that errors associated with poor sampling of large particles are small.

[7] Total uncertainty was estimated by combining instrument noise, precision and systematic uncertainties as described by *Anderson et al.* [2003]. We assign a 25% systematic uncertainty to the PSAP data, somewhat larger than the 20% recommended by *Bond et al.* [1999] to account for unknown accuracy of the internal flow meter. We assign a 10%

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Table 1. Derived Parameters Used for Closure Tests

Parameter	Derivation	Instruments Used
	Layer	
ω_{LAYER}	$\int_{Z\,\mathrm{min}}^{Z\,\mathrm{max}} \sigma_s(z)dz \Big/ \int_{Z\,\mathrm{min}}^{Z\,\mathrm{max}} \sigma_e(z)dz$	Airborne in situ[a]
	Retrieval based on the difference in the net flux at the top and bottom of the layer	Airborne remote sensing[b,c]
τ_{LAYER}	$\int_{Z\,\mathrm{min}}^{Z\,\mathrm{max}} \sigma_e(z)dz$	Airborne in situ[a]
	$\tau_{\mathrm{Zmax}} - \tau_{\mathrm{Zmin}}$ (τ from direct solar beam measurements)	Airborne remote sensing[c]
	Column	
ω_{COLUMN}	Assumption: $\omega_{\mathrm{COLUMN}} = \omega_{\mathrm{LAYER}}$	Airborne in situ[a]
	Inversion based on τ and radiances	Ground-Based Remote Sensing[d]
τ_{COLUMN}	$\tau_{\mathrm{BELOW,IS}} + \tau_{\mathrm{LAYER,IS}} + \tau_{\mathrm{ALOFT,RS}}$	Airborne in situ[a]
	$\overline{\sigma}_{e,LAYER} \int_{Z_0}^{Z\,\mathrm{min}} dz + \int_{Z\,\mathrm{min}}^{Z\,\mathrm{max}} \sigma_e(z)dz + \tau_{Z\,\mathrm{max}}$	
	τ from direct solar beam measurements	Ground-Based Remote Sensing[d]

[a]MS Electron 3-Wavelength Integrating Nephelometer and Particle and Soot Absorption Photometer [*Magi et al.*, 2003].
[b]NASA Ames Solar Spectral Flux Radiometer [*Bergstrom et al.*, 2003].
[c]NASA Ames Airborne Tracking 14-Channel Sun Photometer [*Schmid et al.*, 2003].
[d]Aerosol Robotic Network (AERONET) sun photometer/radiometer [*Eck et al.*, 2003].

systematic uncertainty to the nephelometer, again slightly larger than the literature recommendation of 7% [*Anderson et al.*, 1996].

6. Discussion

[22] There are advantages and limitations to both the in situ and AERONET approaches. AERONET data provide excellent temporal coverage but this is limited to specific sites. While the seven AERONET sites used here are broadly distributed, such that regional coverage is good, the aircraft has the advantage of offering access to all locations. Moreover, its ability to sample a wide area in a relatively short space of time provides excellent information on small scale variability. However, the aircraft only samples any particular location for a short time period. The AERONET method directly observes the undisturbed ambient aerosol; however, the retrieval of ω_{550} requires a complex inversion with many assumptions and requires high aerosol loading ($\tau_{440} \geq 0.5$). The in situ method is a direct measurement of scattering and absorption that performs well down to modest aerosol concentrations ($\sigma_s > 15\ \mathrm{Mm}^{-1}$); however, it involves removing the aerosol from the ambient environment with potential sampling losses and other artifacts. Clearly, these approaches are complementary. Agreement for collocated comparisons (Section 4) increases confidence in the accuracy of each method. Agreement in the regional means (Section 5) increases confidence that representative sampling was achieved by each method.

[23] As mentioned in Section 1, Version 2 AERONET retrievals of ω are lower than those of Version 1 over bright surfaces. The difference can be significant. For example, *Haywood et al.* [2003] reported agreement within 0.01 when comparing in situ derived, spectral ω at Etosha Pan to the Version 1 AERONET retrievals. Repeating the comparison using Version 2 data now gives discrepancies >0.04 at each wavelength.

[24] AERONET inversion-based retrievals of ω are widely used in climate forcing estimates [*Bellouin et al.*, 2003; *Chung et al.*, 2005; *Myhre et al.*, 2003; *Procopio et al.*, 2004; *Sato et al.*, 2003; *Takemura et al.*, 2002] and in the validation of satellite retrievals [*Torres et al.*, 2005]. The uncertainty of Version 1 AERONET-derived ω has been assessed theoretically [*Dubovik et al.*, 2000] but rarely empirically. We are aware of only two prior tests. One, off the U.S. East Coast, indicated a substantial discrepancy (AERONET lower than in situ by 0.07); however, because of low τ_{550} (0.26) and possible sampling errors, the authors could not determine whether this discrepancy was significant [*Magi et al.*, 2005]. Using Version 2 retrieved ω data, the discrepancy was reduced to 0.06 (B. Magi, personal communication, 2007). The other is the *Haywood et al.* [2003] study mentioned above. By providing five direct comparisons and carefully assessing the discrepancies with respect to the estimated uncertainties, the present work adds substantially to current understanding of AERONET retrieval accuracy. However, many more such studies are required before it can be said that AERONET uncertainty and domain of validity for this parameter have been properly assessed.